Poll Res. 44 (3–4) : 256-265 (2025)

ISSN 0257–8050

DOI No.: http://doi.org/10.53550/PR.2025.v44i03-04.016
Journal Home Page: www.envirobiotechjournals.com

MICROPLASTIC CONTAMINATION IN THE AIR-BREATHING SEA SLUG *PERONINA TENERA* (STOLICZKA, 1869): A PRELIMINARY REPORT

SOURAV BAR[1], JHUMPA MAJHI[2], SOUMIK DHARA[3] AND SUDIPTA KUMAR GHORAI[4*]

[1,2,4]Coastal Environmental Studies Research Centre of Egra SSB College under Vidyasagar University Purba Medinipur, Egra, W.B., India
[3]Department of Zoology, Vidyasagar University, Midnapore, West Bengal, India

(Received 6 February, 2025; Accepted 14 April, 2025)

ABSTRACT

Microplastic contamination was assessed in the air-breathing sea slug *Peronina tenera* (Stoliczka, 1869), collected from the Subarnarekha estuary in the northeastern Bay of Bengal. This study aimed to evaluate the abundance, size, colour, and polymer composition of microplastics in the tissues of these estuarine organisms. Ten specimens were sampled from Talsari, Odisha (21°36′2.29″N, 87°27′13.9″E) in April 2024. The concentration of microplastics ranged from 3.72 to 13.51 particles per gram of tissue, with an average of 6.47 particles. Among the different size classes, smaller microplastics (50–500 µm) were the most abundant, and blue-coloured microplastics were the most commonly observed. Raman spectroscopy analysis identified five polymer types: polyethylene terephthalate (PET), polyvinyl chloride (PVC), polystyrene (PS), and polyethylene (PE), all of which are widely used in packaging, textiles, and industrial applications. The pollution load index (PLI) averaged 1.29, indicating significant contamination levels in this estuarine environment. The presence of these microplastics suggests multiple potential sources, including the degradation of plastic waste from fishing nets, ropes, and gear discarded by the fishing industry, as well as synthetic fibers from textile washing and the breakdown of single-use plastic packaging. The accumulation of these microplastics in *P. tenera* highlights their bioavailability in estuarine food chains, raising serious ecological concerns about trophic transfer, bioaccumulation in higher organisms, and potential long-term impacts on aquatic biodiversity.

KEY WORDS : Microplastic, Pollution, Sea slug, Bay of Bengal, Contamination

INTRODUCTION

As microplastic contamination is so common and has significant negative impacts on marine ecosystems, it has emerged as a serious environmental concern (Choudhury *et al.*, 2018). These tiny plastic particles-which are typically less than 5 mm-are either released into the environment directly through products like microbeads or arise from the disintegration of bigger plastic components. Microplastics may linger in marine environments for a long time, and a range of marine creatures, including bigger species, can readily consume them due to their small size (Andrady, 2011; Cole *et al.*, 2011). Marine ecosystems are particularly vulnerable to microplastic pollution due to the widespread use and disposal of plastic materials in coastal regions. Fishing activities, aquaculture, and improper waste management contribute significantly to microplastic accumulation in estuarine and marine environments. Abandoned fishing gear, synthetic ropes, and plastic packaging degrade over time, releasing secondary microplastics into the water column and sediments (Barrows *et al.*, 2018). Additionally, microfibers from synthetic textiles, released through domestic and industrial wastewater, have been identified as a major source

of microplastic pollution in coastal waters (Acharya *et al.,* 2021). These persistent plastic fragments interact with biota in complex ways, impacting both pelagic and benthic organisms.

The impact of microplastic ingestion on marine invertebrates is increasingly being studied, yet many questions remain regarding species-specific responses. Laboratory and field studies suggest that microplastics can cause oxidative stress, alter metabolic processes, and impair reproduction in molluscs, crustaceans, and annelids (Pires *et al.,* 2022; Zhang *et al.,* 2023; Trestrail *et al*., 2020). These findings indicate that prolonged exposure to microplastics could lead to population-level effects, particularly in species that play critical roles in nutrient cycling and habitat structuring. As a soft-bodied benthic invertebrate, *P. tenera* may be particularly vulnerable to such impacts, making it an important candidate for studying the ecological consequences of plastic pollution. Because of its benthic feeding habits, the air-breathing sea slug *Peronina tenera* (Stoliczka, 1869) that lives in intertidal zones is probably at danger of microplastic exposure. This species consumes organic materials that are often found on the bottom, where microplastics tend to gather (Bour *et al*., 2018). Marine species that consume microplastics may have a number of negative consequences, including physical obstructions in their digestive tracts, a reduction in their capacity to absorb nutrients (Guzzetti *et al*., 2018), and exposure to harmful substances that stick to the surfaces of the plastic (Rochman, 2018). Although there is still much to learn about the effects of microplastic pollution on invertebrates such as *P. tenera*, first results are concerning. Because of their high sensitivity to environmental changes, marine slugs are used as bioindicators to measure pollution levels in coastal environments (Marigómez *et al*., 1998). Determining the degree of microplastic consumption by *P. tenera* can shed light on the broader effects of plastic contamination on marine life and food webs.

Given the increasing global awareness of plastic pollution, studies on microplastic ingestion by benthic organisms can provide valuable data for environmental monitoring and conservation strategies (Vecchi *et al*., 2021). Regulatory efforts, such as restrictions on single-use plastics and improvements in waste management systems, are essential to mitigating the spread of microplastics (Singh and Biswas, 2023). However, further research is needed to evaluate long-term trends in microplastic accumulation, their effects on biodiversity, and potential mitigation approaches. The current study aims to quantify the microplastic burden in *P. tenera* from the Subarnarekha estuary and assess its implications for marine food webs and ecosystem health.

MATERIAL AND METHODS

Sample collection and processing

For the microplastic analysis in the air-breathing sea slug *P. tenera* (Stoliczka, 1869), a standard method was followed for sample collection and processing. Ten specimens of *P. tenera* (Fig. 1B, C) were gathered from a selected station (21°3622.293N 87°27213.93E) in Talsari, Odisha, during April 2024 (see Fig. 1A). To maintain tissue integrity, the collected specimens were stored at -20 °C. The body weight of each specimen was recorded, with total body weights ranging from 1.11 g to 3.22 g. After measuring the weight, all specimens were washed thoroughly using distilled water to remove any external adherence of microplastics. Following this, the entire specimens underwent chemical digestion for further analysis.

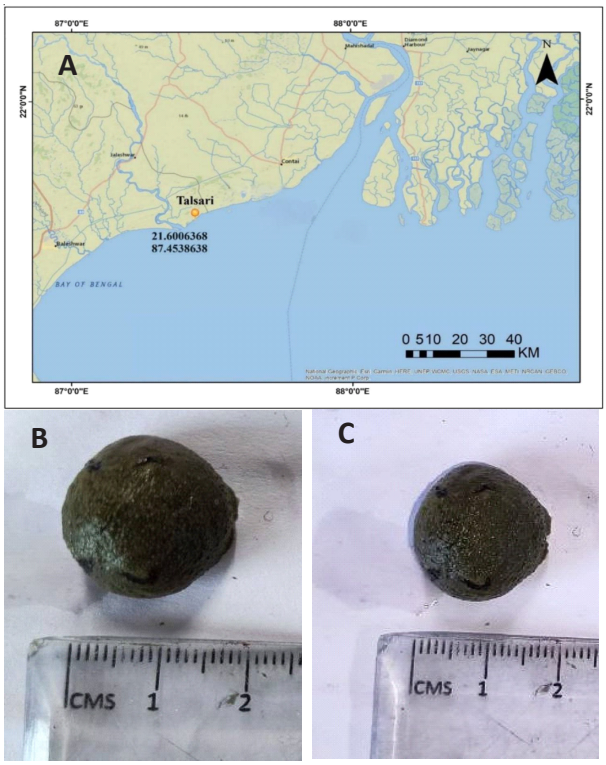

Fig. 1. (A) Samples of *Peronina tenera* were collected from the Talsari, located on the northeastern coast of the Bay of Bengal in Odisha. (B)& (C) Collected sample of *P. tenera*.

Microplastic analysis

Microplastic extraction, observation, and identification followed established protocols with minor adjustments. Whole tissue samples were processed according to the method described by Gong *et al.* (2021), where each sample was treated with a 10% KOH (Merck) solution, using 20 ml of solution per gram of wet tissue. The treated samples were then heated at 70°C to ensure complete digestion. Following digestion, density separation was carried out using 6 g of 5M NaCl per 20 ml solution (Dellisanti *et al*., 2023; Banik *et al*., 2022), allowing for the effective separation of digested organic material from microplastics. The resulting mixture was vacuum filtered through Whatman GF/C glass microfiber filter papers (0.1 µm pore size, 47 mm diameter, GE Healthcare Pvt. Ltd.) to isolate the microplastics. Precautions were taken throughout the extraction process to avoid contamination, including covering the samples with aluminium foil. Once the microplastics were extracted, the filter papers were carefully placed in clean petri dishes for further analysis.

To effectively observe and identify the microplastics (MPs), a combination of visual observation, image analysis, and spectroscopic techniques was utilized. The size and colour of the microplastics on the filter papers were first examined under a stereomicroscope (MSZ-TR trinocular, Magnus). Precise size measurements were recorded using Magvision image analysis software, and images were captured with a digital camera (MagCam DC-5, Magnus) attached to the stereomicroscope. Following this, the colour of the microplastics was visually analysed for identification. To verify the chemical composition of the microplastics, Confocal Raman Microscopy (LabRAM HR Evolution, HORIBA Scientific) was employed. Spectral data were collected across a wide range (500-4000 cm^{-1}) and compared against standard spectral libraries specific to plastic polymers for identification. During analysis, special attention was given to achieving a minimum 70% confidence level in spectral matching or confirming a reliable match through visual inspection. This approach ensures accurate and robust identification of the plastic polymer composition present in the microplastics.

Quality control

Several crucial steps were followed during sample processing to minimize contamination from both internal and external sources (Shruti and Kutralam-Muniasamy, 2023). First, all chemical solutions used for microplastic extraction were filtered through glass microfiber filter paper (0.1 µm pore size, 47 mm diameter, Whatman GF/C) to eliminate any potential contaminants, ensuring that the chemicals were free of microplastic particles. Additionally, Milli-Q water, commonly used in laboratory procedures, was similarly filtered through the same type of filter paper to guarantee the purity of the water used in the extraction process. All equipment involved in sample processing was thoroughly rinsed with Milli-Q water two to three times to prevent contamination. Petri dishes used for sample transfer were also washed with Milli-Q water before placing the filter paper in them. To protect the samples from external contamination, such as airborne microplastic particles or dust, aluminium foil was used to cover them throughout the processing, thereby preserving sample integrity. To further ensure accuracy, a blank sample was taken at each stage of processing as a negative control (Shruti and Kutralam-Muniasamy, 2023). This allowed for a baseline measurement to differentiate genuine microplastic particles from potential contaminants introduced during processing. Only a minimal amount of microplastics was detected in the blank samples, which served as negative controls. The average microplastic contamination in these blanks was 0.5 particles, and this value was subtracted from the results of the target samples to ensure accurate reporting.

Pollution load analysis

The Pollution Load Index (PLI) methodology (Tomlinson *et al*., 1980) was applied to assess microplastic contamination in the body tissues of *P. tenera*. This method systematically evaluates the potential risk of microplastic pollution across per gram body tissue of all specimens, drawing on existing data regarding microplastic abundance (Wang and Chen, 2023). The PLI for per gram body tissue of each individual i was calculated using the formula:

$$CF_i = C_i / C_0$$

$$PLI_i = \sqrt{CF_i}$$

where C_i is the concentration factor for individual i, representing the microplastic abundance, and C_0 refers to the baseline microplastic abundance. Since no standard reference value for microplastic contamination in *P. tenera* exists, C_0 was set to the lowest recorded microplastic abundance in the

species (Wang and Chen, 2023). It is essential to note that while different choices for C_0 may impact the absolute PLI values, the relative comparison between individuals remains unaffected. This ensures that the risk assessment of microplastic pollution across different individuals of *P. tenera* is still reliable and valid.

Statistical analysis

A robust statistical analysis was performed to assess the variability in microplastic size and colour in *P. tenera*. Given the non-normal distribution and unequal variances in the dataset, a Kruskal-Wallis test was applied to compare differences across the observed size classes (50-500 μm, 500-1000 μm, 1000-2000 μm, and 2000-4000 μm) and colour categories. This non-parametric test is appropriate when parametric assumptions are not met, ensuring a reliable comparison of microplastic characteristics. A p-value threshold of less than 0.05 was considered statistically significant, indicating substantial differences in the distribution of microplastic sizes and colours.

RESULTS AND DISCUSSION

Numerous studies have documented the presence of microplastics in marine and freshwater invertebrates, highlighting their potential to disrupt feeding behaviour, growth, reproduction, and ecosystem functions (Table 1). The ingestion and accumulation of microplastics vary based on species, habitat, and trophic interactions, with some studies also linking microplastics to the transfer of contaminants and antibiotic resistance genes (Table 1). Despite extensive research, knowledge gaps remain regarding the long-term ecological consequences and trophic transfer of microplastics in benthic food webs.

The air-breathing sea slug *P. tenera* plays an

Table 1. Recent Studies on the Effects of Microplastics on Benthic Invertebrates (2020-2025)

Year	Study	Focus of Study
2025	Fang *et al.*	Microplastic occurrence and influencing factors in surface water, sediments, and benthic macro invertebrates in Huangbai River.
2025	Ma *et al.*	Microplastic degradation promotes the conjugative transfer of antibiotic resistance genes in macro benthic invertebrate guts.
2025	Gonzalez-Pineda *et al.*	Experimental ingestion of microplastics in three Antarctic benthic species.
2024	Sfriso *et al.*	Microplastic accumulation and ecological impacts on benthic invertebrates through a microcosm experiment.
2024	Xie *et al.*	Influence of habitat, feeding habits, and trophic level on microplastic distribution in 16 benthic organisms in Haizhou Bay, China.
2023	Porter *et al.*	Species traits and feeding ecology influence microplastic burden in benthic invertebrates across biogeographical provinces.
2023	Prata *et al.*	Uptake dynamics and adverse effects of microplastics on *Chironomus riparius*, a freshwater benthic invertebrate.
2023	Zhang *et al.*	Microplastic load in benthic fauna from Jiaozhou Bay, China.
2023	de Ruijter *et al.*	Effects of standardized heterogeneous microplastic mixtures on 16 benthic invertebrate species.
2022	Silva *et al.*	Microplastics impact benthic invertebrate communities and ecosystem functioning in artificial freshwater streams.
2022	Stankovic *et al.*	*In situ* effects of a microplastic mixture on benthic macroinvertebrate community structure in a freshwater pond.
2021	Vecchi *et al.*	Field evidence of microplastic interactions in marine benthic invertebrates.
2021	Berlino *et al.*	Global-scale meta-analysis of the effects of microplastics on functional traits of aquatic benthic organisms.
2021	Huang *et al.*	Microplastics impact microbial nitrogen removal mediated by benthic invertebrates, affecting ecosystem functioning.
2021	Gallitelli *et al.*	Preliminary indoor evidence of microplastic effects on freshwater benthic macroinvertebrates.
2020	Bellasi *et al.*	Review of microplastic contamination in freshwater environments, focusing on interactions with sediments and benthic organisms.
2020	Sfriso *et al.*	Microplastic accumulation in benthic invertebrates in Terra Nova Bay, Antarctica.

essential role in promoting coastal ecosystem stability. As a benthic species, it actively participates in nutrient recycling within sediment environments, aiding in the overall productivity and functionality of the benthic community (Welsh, 2003). Additionally, *P. tenera* serves as a key prey species for various marine organisms, forming a crucial link between lower and higher trophic levels and impacting food web dynamics in intertidal zones (Paine, 1966). To date, no studies have been conducted on microplastic pollution in *P. tenera*. In this investigation, 10 individuals of *P. tenera* were selected to assess the variability of microplastic contamination across different specimens.

Abundance, size and colour of microplastic

The analysis of *P. tenera* revealed variable microplastic concentrations in body tissue, ranging from 3.72 to 13.51 particles per gram across the 10 specimens (Fig. 2A). On average, 6.47 microplastic particles were found per gram of body tissue. This variation in microplastic abundance may be linked to several factors, suggesting that the specimens experienced different levels of exposure to microplastics in their benthic estuarine environment. As these organisms feed and process food, they are more likely to ingest microplastic particles present in the surrounding water and sediment.

The examination of microplastic size distribution in the body tissue of *P. tenera* classified the microplastics into four size ranges, from 50-500 µm to 2000-4000 µm (Fig. 2b). The average abundance of microplastics per gram of tissue across the ten samples showed the highest number in the 50-500 ìm size range, with an average of 2.62 particles, followed by 1.38 particles in the 1000-2000 µm range, 1.35 in the 500-1000 µm range, and 1.11 in the 2000-4000 µm range (Fig. 2B). A Kruskal-Wallis test

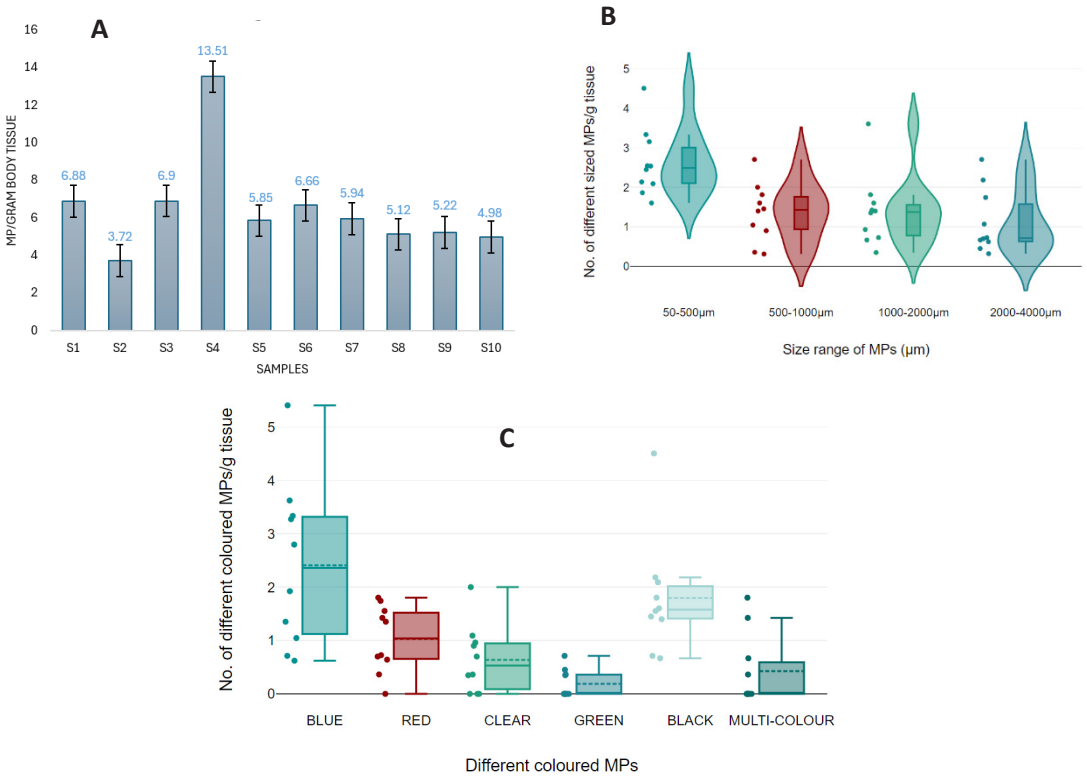

Fig. 2. (A) shows the abundance of microplastic particles per gram of body tissue across 10 different samples (S1-S10). The highest microplastic concentration was observed in sample S4 (13.51 MP/g tissue), while the lowest was recorded in sample S2 (3.72 MP/g tissue). Error bars represent standard deviations. (B) Violin plot illustrates the number of microplastics per gram of body tissue across four different size ranges (50-500 µm, 500-1000 µm, 1000-2000 µm, and 2000-4000 µm). Microplastics in the 50-500 µm size range are the most abundant, while larger size categories show a lower concentration. Boxplots within the violin plots show the median and interquartile ranges.(C) Boxplot displaying the number of different coloured microplastic particles per gram of body tissue. Blue microplastics were the most abundant, followed by red, black, clear, multi-coloured, and green particles. The distribution shows variability, with blue microplastics exhibiting the widest range.

revealed a statistically significant difference in microplastic size distribution across the four size ranges ($\div^2 = 13.85$, $p = 0.003$). This indicates that the variation in size distribution is meaningful, with fewer large-sized microplastics observed, highlighting a predominance of smaller microplastic particles.

Six distinct colours of microplastics were observed: black, blue, clear (transparent), green, red, and multi-coloured (Fig. 2C). Among these, blue microplastics (Fig. 3A) were the most prevalent, with an average of 2.40 particles per gram of body tissue. Black microplastics followed as the second most common, averaging 1.79 particles per gram of tissue. Red (Fig. 3B), clear, multi-coloured, and green microplastics were progressively less abundant, with averages of 1.03, 0.63, 0.42, and 0.18 particles per gram, respectively. This variation in colour distribution likely reflects differing sources and degradation processes that influence microplastic composition across marine environments (Boškoviæ *et al.*, 2022). A Kruskal-Wallis test conducted on the six colour categories showed a statistically significant difference in abundance ($\chi^2 = 29.54$, $p = 0.000013$) among the plastic colour groups.

Chemical identification of MPs

The microplastic samples collected from *P. tenera* were chemically characterized using confocal Raman spectroscopy. This analysis revealed the presence of five distinct plastic polymers: polyethylene terephthalate (PET), polyvinyl chloride (PVC), polystyrene (PS), and polyethylene (PE) (Fig. 3C, D). Among these, polymers such as PVC, PS, and PET are widely acknowledged as environmental pollutants in their microplastic form (Changmai *et al.*, 2024; Liu *et al.*, 2024; Sun *et al.*, 2024).

Comparison with other species

Microplastic (MP) concentrations in *P. tenera* (3.72–13.51 MP/g, avg. 6.47 MP/g) were higher than those reported for *Telescopium telescopium* (1-4 MP/g, avg. 1.12 MP/g) from the mangrove forests of Versova Creek, Mumbai (Dar *et al.*, 2023) but lower than *Pseudomino liabiangulosa* (9.13 MP/g) from the Southwest coast of India (Nikhil *et al.*, 2024). While all studies reported a predominance of smaller MPs (<500 µm), *P. tenera* showed a broader size range (50–4000 µm), similar to *Pseudomino liabiangulosa* and *Tesseracme quadrapicalis* (5.96 MP/g), where most MPs were <250 µm (Nikhil *et al.*, 2024). Polymer composition varied, with *P. tenera* containing polyethylene terephthalate (PET), polyvinyl chloride (PVC), polystyrene (PS), and polyethylene (PE), while *T. telescopium* had PE,

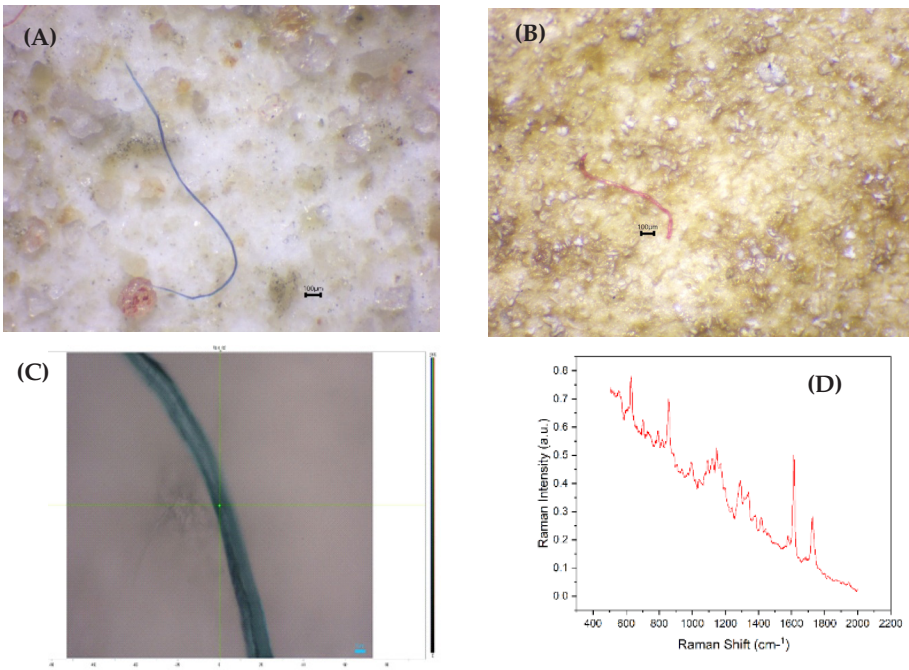

Fig. 3. (A) & (B) represent blue and red coloured microplastic fibres respectively found in body tissue of air breathing sea slug.(C) is the confocal Raman microscopic image polyethylene and (D) is the Raman spectra of polyethylene (PE).

polypropylene (PP), and polyurethane (PU), and molluscs from the Southwest coast contained 11 polymer types, dominated by PE and PP (Dar *et al.*, 2023; Nikhil *et al.*, 2024). The higher MP burden in scavenging gastropods (*P. tenera* and *Pseudomino liabiangulosa*) suggests a greater risk due to their benthic feeding habits, in contrast to lower accumulation in suspension and deposit-feeding bivalves. These findings highlight species-specific MP accumulation patterns and emphasize the ecological risk of MPs in coastal ecosystems, reinforcing the potential of molluscs as bioindicators of marine pollution.

Pollution load

The risk assessment of microplastics in *P. tenera* was carried out by calculating the Pollution Load Index (PLI) for each collected sample. The PLI was derived from the microplastic abundance per gram of tissue, with the lowest recorded abundance (3.72 microplastics per gram of tissue) set as the baseline for calculations (Wang and Chen, 2023). The analysis revealed an average PLI of 1.29 per gram of tissue in *P. tenera*. A PLI value exceeding 1 indicates a concerning level of microplastic contamination in the tissue samples of this air-breathing sea slug.

CONCLUSION

The detection of microplastics in *P. tenera* underscores significant pollution in the northeastern Bay of Bengal, particularly in the Subarnarekha estuary. Elevated Pollution Load Index (PLI) values exceeding 1 in tissue samples reflect critically high contamination levels. The presence of diverse microplastic polymers, including PET, PVC, PS, and PE, suggests sources such as fishing nets and plastic wastes from tourism activities, with blue and black microplastics being particularly prevalent. These findings indicate the estuary's role as a hotspot for microplastic accumulation, posing risks to benthic organisms and their habitats. The ingestion of microplastics by *P. tenera* highlights a potential pathway for trophic transfer within the ecosystem. Given the significant bioavailability of microplastics in estuarine environments, their persistence in benthic organisms like *P. tenera* raises concerns about long-term ecological consequences, including bioaccumulation in higher trophic levels. The predominance of smaller-sized microplastics further suggests their potential for cellular uptake, leading to physiological stress and altered metabolic processes in marine invertebrates. Additionally, the strong correlation between microplastic ingestion and feeding strategies emphasizes the need for further research on species-specific vulnerabilities. These findings reinforce the urgency of implementing stringent plastic waste management measures to mitigate contamination in ecologically sensitive coastal regions.

Declaration

During the preparation of this work the author(s) used ChatGPT in order to arrange the sentences properly in the manuscript. After using Chat GPT, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Consent to publish

All the authors consented on the publication of any material or information used in this manuscript.

Data availability statement

Supplementary data related to this article can be found, in the Mendeley Data, at DOI: 10.17632/ndgjzkd4ms.1

CRediT authorship contribution statement

Sourav Bar: Writing- original draft, Investigation, software. Soumik Dhara: Methodology, Conceptualization. Jhumpa Majhi: Methodology, Conceptualization, Investigation. Sudipta Kumar Ghorai: Writing- review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing in interests: SOURAV BAR and JHUMPA MAJHI report financial support was provided by University Grants Commission. SOURAV BAR and JHUMPA MAJHI report a relationship with University Grants Commission that includes funding grants (fellowship and contingency). If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGEMENT

We express our sincere gratitude to the University

Grants Commission (UGC) for their financial assistance through the provision of a fellowship, which has been instrumental in the successful completion of this study. We extend our sincere gratitude to all the members of the Coastal Ecology Research Laboratory (CERL) at Egra SSB College for their invaluable support and assistance. We sincerely thank the Indian Science, Technology, and Engineering Facilities Map (I-STEM) and the Indian Institute of Technology (Indian School of Mines), Dhanbad, for providing access to the Confocal Raman Spectroscopy facility. Their support has been instrumental in facilitating this research.

REFERENCES

Acharya, S., Rumi, S.S., Hu, Y. and Abidi, N. 2021. Microfibers from synthetic textiles as a major source of microplastics in the environment: A review. *Textile Research Journal*. 91(17-18): 2136-2156.doi.org/10.1177/0040517521991244

Andrady, A.L. 2011. Microplastics in the marine environment. *Marine Pollution Bulletin.* 62(8): 1596-1605.doi.org/10.1016/j.marpolbul.2011.05.030

Banik, P., Hossain, M.B., Nur, A.A.U., Choudhury, T. R., Liba, S.I., Yu, J. and Sun, J. 2022. Microplastics in sediment of Kuakata Beach, Bangladesh: occurrence, spatial distribution, and risk assessment. *Frontiers in Marine Science.* 9: 860989.doi.org/10.3389/fmars.2022.860989

Barrows, A.P.W., Cathey, S.E. and Petersen, C.W. 2018. Marine environment microfiber contamination: Global patterns and the diversity of microparticle origins. *Environmental Pollution*. 237: 275-284. doi.org/10.1016/j.envpol.2018.02.062

Bellasi, A., Binda, G., Pozzi, A., Galafassi, S., Volta, P. and Bettinetti, R. 2020. Microplastic contamination in freshwater environments: A review, focusing on interactions with sediments and benthic organisms. *Environments*. 7(4): 30. doi.org/10.3390/environments7040030

Berlino, M., Mangano, M.C., De Vittor, C. and Sarà, G.J.E.P. 2021. Effects of microplastics on the functional traits of aquatic benthic organisms: A global-scale meta-analysis. *Environmental Pollution.* 285: 117174.doi: 10.1016/j.envpol.2021.117174.

Boškoviæ, N., Joksimoviæ, D., Peroševiæ-Bajèeta, A., Pekoviæ, M. and Bajt, O. 2022. Distribution and characterization of microplastics in marine sediments from the Montenegrin coast. *Journal of Soils and Sediments.* 22(11): 2958-2967.doi.org/10.1007/s11368-022-03166-3

Bour, A., Avio, C.G., Gorbi, S., Regoli, F. and Hylland, K. 2018. Presence of microplastics in benthic and epibenthic organisms: Influence of habitat, feeding mode and trophic level. *Environmental Pollution.* 243: 1217-1225. doi: 10.1016/j.envpol.2018.09.115.

Changmai, U., Sahana, S. K., Kumar, N., Borah, B., Chikkaputtaiah, C., Saikia, R. and Phukan, T. 2024. Impact of polyvinyl chloride (PVC) microplastic on growth, photosynthesis and nutrient uptake of *Solanum lycopersicum* L. (Tomato). *Environmental Pollution.* 349: 123994.doi: 10.1016/j.envpol.2024.123994.

Choudhury, A., Sarmah, R., Bhagabati, S., Dutta, R., Baishya, S., Borah, S. and Borah, K. 2018. Microplastic pollution: An emerging environmental issue. *Journal of Entomology and Zoology Studies.* 6(6): 340-344.

Cole, M., Lindeque, P., Halsband, C. and Galloway, T.S. 2011. Microplastics as contaminants in the marine environment: a review. *Marine Pollution Bulletin.* 62(12): 2588-2597.doi.org/10.1016/j.marpolbul.2011.09.025

Dar, J.Y., Saha, M., Taghizade, Z., Kantharajan, G. and Rajendran, K.V. 2023. Microplastics contamination in the gastropod, Telescopium telescopium, from the mangrove area of Versova Creek, Mumbai, India: Microplastics in the gastropod. *International Journal of Aquatic Biology*. 11(5): 417-430.doi.org/10.22034/ijab.v11i5.1940

de Ruijter, V.N., Hof, M., Kotorou, P., van Leeuwen, J., van den Heuvel-Greve, M.J., Roessink, I. and Koelmans, A.A. 2023. Microplastic effect tests should use a standard heterogeneous mixture: Multifarious impacts among 16 benthic invertebrate species detected under ecologically relevant test conditions. *Environmental Science & Technology.* 57(48): 19430-19441.doi: 10.1021/acs.est.3c06829.

Dellisanti, W., Leung, M.M.L., Lam, K.W.K., Wang, Y., Hu, M., Lo, H. S. and Fang, J.K.H. 2023. A short review on the recent method development for extraction and identification of microplastics in mussels and fish, two major groups of seafood. *Marine Pollution Bulletin.* 186: 114221.doi: 10.1016/j.marpolbul.2022.114221.

Fang, Z.J., Li, W.M., Yan, K., Xiao, M., Li, Y.C., Ding, S. and Li, H. 2025. Occurrence Characteristics and Influencing Factors of Microplastics in Surface Water, Sediments, and Benthic Macroinvertebrates in Huangbai River. *Huan Jingkexue Huanjingkexue*. 46(2): 1181-1192.doi: 10.13227/j.hjkx.202401168.

Gallitelli, L., Cera, A., Cesarini, G., Pietrelli, L. and Scalici, M. 2021. Preliminary indoor evidences of microplastic effects on freshwater benthic macroinvertebrates. *Scientific Reports.* 11(1): 720.doi: 10.1038/s41598-020-80606-5.

Gong, Y., Wang, Y., Chen, L., Li, Y., Chen, X. and Liu, B. 2021. Microplastics in different tissues of a pelagic

squid (*Dosidicus gigas*) in the northern Humboldt Current ecosystem. *Marine Pollution Bulletin.* 169: 112509.doi: 10.1016/j.marpolbul.2021.112509.

Gonzalez-Pineda, M., Avila, C., Lacerot, G., Lozoya, J.P., de Mello, F.T., Faccio, R. and Salvadó, H. 2025. Experimental ingestion of microplastics in three common Antarctic benthic species. *Marine Environmental Research*. 204: 106879. doi:10.1016/j.marenvres.2024.106879.

Guzzetti, E., Sureda, A., Tejada, S. and Faggio, C. 2018. Microplastic in marine organism: Environmental and toxicological effects. *Environmental Toxicology and Pharmacology*. 64: 164-171.doi: 10.1016/j.etap.2018.10.009.

Huang, Y., Li, W., Gao, J., Wang, F., Yang, W., Han, L. and Yao, J. 2021. Effect of microplastics on ecosystem functioning: Microbial nitrogen removal mediated by benthic invertebrates. *Science of the Total Environment*. 754: 142133.doi: 10.1016/j.scitotenv.2020.142133.

Liu, S., Li, Y., Wang, F., Gu, X., Li, Y., Liu, Q. and Bai, F. 2024. Temporal and spatial variation of microplastics in the urban rivers of Harbin. *Science of the Total Environment*. 910: 168373.doi: 10.1016/j.scitotenv.2023.168373.

Ma, J., Lv, C., Gong, Z., Zhang, K., Wang, S., Li, R. and Ding, C. 2025. Promotion of microplastic degradatiọn on the conjugative transfer of antibiotic resistance genes in the gut of macrobenthic invertebrates. *Ecotoxicology and Environmental Safety*. 293: 117999.doi.org/10.1016/j.ecoenv.2025.117999

Marigómez, I., Kortabitarte, M. and Dussart, G.B.J. 1998. Tissue-level biomarkers in sentinel slugs as cost-effective tools to assess metal pollution in soils. *Archives of Environmental Contamination and Toxicology*. 34: 167-176.doi.org/10.1007/s002449900301

Nikhil, V.G., Amritha, G.G., Ranjeet, K. and Varghese, G.K. 2024. Distribution of microplastics in seafloor sediments and their differential assimilation in nearshore benthic molluscs along the south-west coast of India. *Environmental Pollution.* 344: 123350.doi: 10.1016/j.envpol.2024.123350.

Paine, R.T. 1966. Food web complexity and species diversity. *The American Naturalist.* 100(910): 65-75.doi:10.1086/282400

Pires, A., Cuccaro, A., Sole, M. and Freitas, R. 2022. Micro (nano) plastics and plastic additives effects in marine annelids: A literature review. *Environmental Research.* 214: 113642.doi: 10.1016/j.envres.2022.113642.

Porter, A., Godbold, J.A., Lewis, C.N., Savage, G., Solan, M. and Galloway, T.S. 2023. Microplastic burden in marine benthic invertebrates depends on species traits and feeding ecology within biogeographical provinces. *Nature Communications*. 14(1): 8023.doi.org/10.1038/s41467-023-43788-w

Prata, J.C., Silva, C.J., Serpa, D., Soares, A.M., Gravato, C. and Silva, A.L.P. 2023. Mechanisms influencing the impact of microplastics on freshwater benthic invertebrates: uptake dynamics and adverse effects on *Chironomus riparius*. *Science of The Total Environment*. 859: 160426. doi.org/10.1016/j.scitotenv.2022.160426

Rochman, C.M. 2018. Microplastics research-from sink to source. *Science.* 360(6384): 28-29.doi: 10.1126/science.aar7734.

Sfriso, A.A., Juhmani, A.S., Tomio, Y., Sfriso, A., Rizzolio, F., Adeel, M. and Mistri, M. 2024. Microplastic accumulation and ecological impacts on benthic invertebrates: Insights from a microcosm experiment. *Marine Pollution Bulletin*. 202: 116231.doi: 10.1016/j.marpolbul.2024.116231.

Sfriso, A.A., Tomio, Y., Rosso, B., Gambaro, A., Sfriso, A., Corami, F. and Munari, C. 2020. Microplastic accumulation in benthic invertebrates in Terra Nova bay (Ross Sea, Antarctica). *Environment International*. 137: 105587.doi: 10.1016/j.envint.2020.105587.

Shruti, V.C. and Kutralam-Muniasamy, G. 2023. Blanks and bias in microplastic research: Implications for future quality assurance. *Trends in Environmental Analytical Chemistry*. 38: e00203.doi.org/10.1016/j.teac.2023.e00203

Silva, C.J., Machado, A. L., Campos, D., Rodrigues, A.C., Silva, A.L.P., Soares, A.M. and Pestana, J.L. 2022. Microplastics in freshwater sediments: Effects on benthic invertebrate communities and ecosystem functioning assessed in artificial streams. *Science of The Total Environment*. 804: 150118.doi: 10.1016/j.scitotenv.2021.150118.

Singh, S. and Biswas, M. K. 2023. Management strategies for single-use plastics: Lessons to learn from Indian approach of minimizing microplastic waste. *Environmental Science: Advances*. *2*(12): 1680-1695.doi.org/10.1039/d3va00222e

Stankovic, J., Miloševic, D., Jovanoviæ, B., Saviæ Zdravkoviæ, D., Petroviæ, A., Rakoviæ, M. and Stojkoviæ Piperac, M. 2022. In situ effects of a microplastic mixture on the community structure of benthic macroinvertebrates in a freshwater pond. *Environmental Toxicology and Chemistry.* 41(4): 888-895.doi: 10.1002/etc.5119.

Sun, Q., Liu, L., Gong, Y. and Liu, P. 2024. Adsorption behavior and interaction mechanism of microplastics with typical hydrophilic pharmaceuticals and personal care products. *Environmental Research.* 244: 117897.doi: 10.1016/j.envres.2023.117897.

Tomlinson, D.L., Wilson, J.G., Harris, C.R. and Jeffrey, D.W. 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index.

Helgoländermeeresuntersuchungen. 33: 566-575.doi.org/10.1007/BF02414780

Trestrail, C., Nugegoda, D. and Shimeta, J. 2020. Invertebrate responses to microplastic ingestion: Reviewing the role of the antioxidant system. *Science of the Total Environment*. 734: 138559.doi: 10.1016/j.scitotenv.2020.138559.

Vecchi, S., Bianchi, J., Scalici, M., Fabroni, F. and Tomassetti, P. 2021. Field evidence for microplastic interactions in marine benthic invertebrates. *Scientific Reports.* 11(1): 20900. doi: 10.1038/s41598-021-00292-9.

Wang, Y. and Chen, X. 2023. Microplastics in a pelagic squid (*Dosidicus gigas*) from the Eastern tropical Pacific Ocean: Characteristics, spatial variation, and preliminary risk assessment. *Frontiers in Environmental Science.* 11: 1069124.doi.org/10.3389/fenvs.2023.1069124

Welsh, D.T. 2003. It's a dirty job but someone has to do it: the role of marine benthic macrofauna in organic matter turnover and nutrient recycling to the water column. *Chemistry and Ecology.* 19(5): 321-342.doi.org/10.1080/0275754031000155474

Xie, S., Song, K., Liu, S., Li, Y., Wang, J., Huang, W. and Feng, Z. 2024. Distribution and characteristics of microplastics in 16 benthic organisms in Haizhou Bay, China: Influence of habitat, feeding habits and trophic level. *Marine Pollution Bulletin.* 199: 115962. doi: 10.1016/j.marpolbul.2023.115962.

Zhang, K., Zheng, S., Liang, J., Zhao, Y., Li, Q., Zhu, M. and Sun, X. 2023. Microplastic load of benthic fauna in Jiaozhou Bay, China. *Environmental Pollution*. 320: 121073.doi: 10.1016/j.envpol.2023.121073.

Zhang, S., Wu, H. and Hou, J. 2023. Progress on the effects of microplastics on aquatic crustaceans: a review. *International Journal of Molecular Sciences*. 24(6): 5523.doi: 10.3390/ijms24065523.